AI-01 Robot Hacker's Manual

Rev 1, 2/08/2008

DISCLAIMER: It is important to say this before we go any further. **Modifying your robot voids the warranty.** Active Innovations cannot be held responsible for a user that modifies the robot or remote in any way. Most hackers are fully aware that the manufacturer never intended for them to touch the "guts". Active Innovations takes this a step further. We know that some of you are going to touch the guts and turn the AI-01 into a robotic slave to follow your own purposes. We made it so that the guts are accessible and usable for those people, but issues like ESD sensitivity alone make it so that if you start tinkering, you acknowledge that you are no longer using the AI-01 as it is primarily intended. The philosophy is one of "You bought it, and you might break it. If you do break it, it stays bought." Similarly, this goes for safety. Active Innovations cannot be held responsible for any injury that occurs to someone that diassembles or otherwise uses the robot or remote for other than its intended purpose.

Introduction:

Purpose: The purpose of this document is to provide technical information to the advanced user of the AI-01 robot. By "advanced" user, I mean someone that wants to use the robot as robotics platform. This kind of user frequently takes a motorized toy abandoned by a 7 year old, and turns it into robot project. The AI-01 was designed to be used by this kind of user out of the box. Unlike most robot toys that have a ROM'd processor that cannot be altered, the AI-01 uses a flash based microcontroller that can be reprogrammed, a user accessible port that makes it easy to reprogram the micro as well as do serial port communication. It has a bi-directional link with an easy to use remote for manual control, but the remote is also reprogrammable and has a serial port. The AI-01's motors are removable, upgradeable and easy to access and be used to drive different actuators than the arms that are built in. We at Active Innovations feel you –the advanced user- will find these features handy in allowing you to create a new robot that does what YOU want.

But, if you want to get in a play or two of robotic football, just put back in the default code and you're ready to hike.

Scope: This manual is a hardware and high level user interface specification document. It does not address software operation for the robot or remote.

Audience: The reader of this manual is assumed to have at least an intermediate level of electronics and software experience. This manual is not intended to be instruction in these fields. Further this is not a beginning robotics manual. The reader is assumed to understand basic robotics concepts. H-bridges, PWM motor control, RF circuit should be terms that cause no confusion.

References: The following documents will be useful to the reader in using the components of the AI-01

References:
Microchip PIC18F65J10 microcontroller Data Sheet (www.microchip.com)
Microchip 18F2321 microcontroller Data Sheet (www.microchip.com)
Nordic nRF24L01 transceiver IC data sheet (www.nordicsemi.com)
Microchip 24L01 EEPROM IC data sheet (www.microchip.com)
ST TIP120 and TIP125 Transistor data sheet (www.st.com)
Sharp GP1UE261XK IR receiver module data sheet

Summary of technical specifications

Feature	Specification
Power	Robot: 9.6V flat pack battery, min 600 mAH rating required Remote: 4 size AAA batteries
Dimensions	7.63 x 6.6 x 12.5 inches (see figure 1 below) Weight: Without battery: 2 pounds 3 oz (1001 grams) With battery: 2 pounds, 8 oz (1151 grams)
Battery life	Robot: 45 minutes with 700 mAH battery Remote: 50 hours with alkalines
Robot locomotion	Differential drive by 2 DC motors each mounted with 2 ½" diameter wheels. Drive DC gear motors (no load) Speed: 152 rpm No load torque: 4.5 kgw.cm Continuous current draw: 220 mA
Robot control	handheld remote control or autonomous and back panel 2 tact swithes 1 three-position switch 1 potentiometer
Range of remote to robot	100 feet outdoors, 50 feet indoors
Robot actuators	All motors have outer case size of x x inches. Double D type mount compatible with Solarbotics gearbox motors and wheels Throwing arm DC gear motor Speed: 280 rpm No load torque: 3.9 kgw.cm Continuous current draw: 500 (startup >1.5A)

	Non throwing arm DC gear motor Speed: 39 rpm No load torque: 5.2 kgw.cm Continuous current draw: 420 mA
Voice playback	20 second capacity minimum with the Winbond ISD17X voice playback IC on main board. Output to 8 ohm speaker located in head.

Table 1: Summary of Technical Features

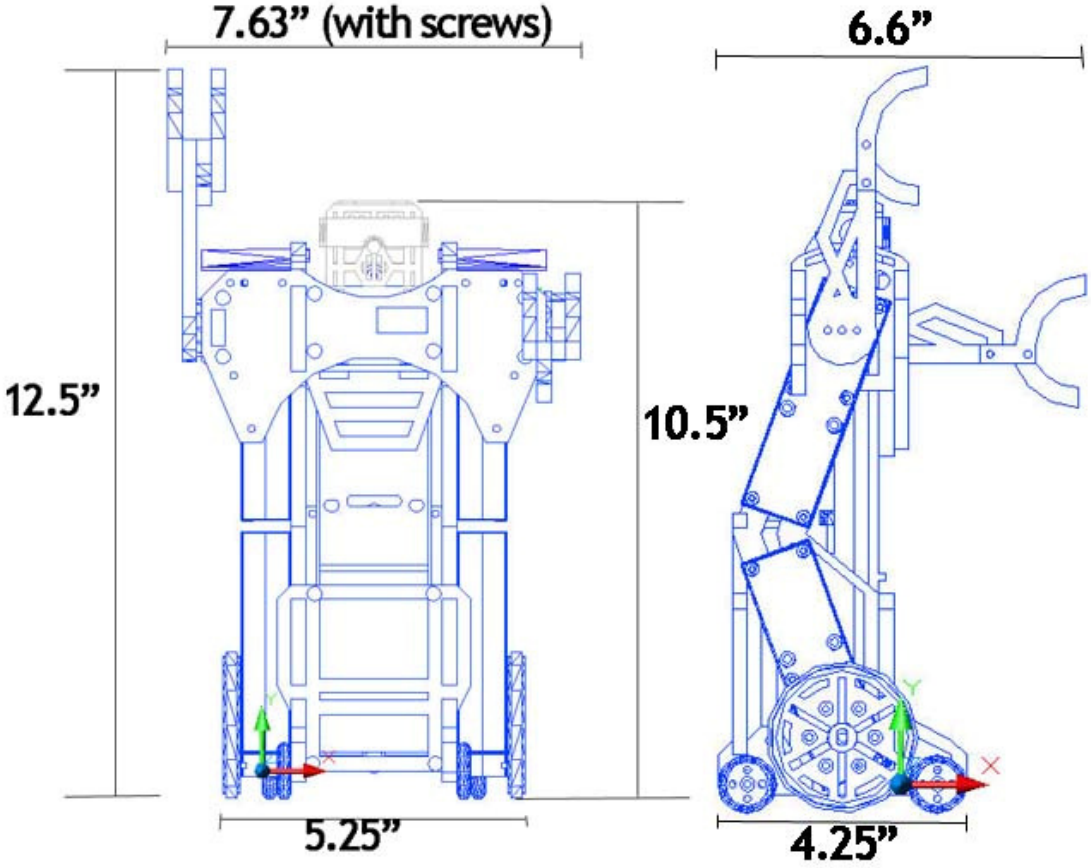

Figure 1: Dimension drawing of robot

Chapter 1: Theory of Operation

Figure 2 below shows a basic level block diagram of the AI-01 robot and remote as a system. Each are standalone devices that have independent processing. But let's first examine briefly how they work together.

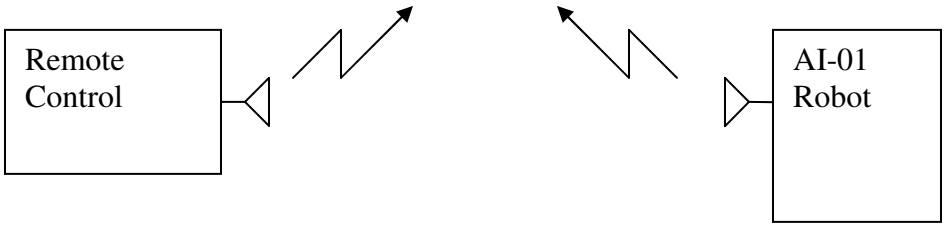

Figure 2: Basic Block Diagram of Remote and Robot System

The AI-01 robot and remote form a bi-directional communication system. Out of the box, the remote control is primarily a transmitter similar to the radio transmitter of an RC car or plane. But if you look on the back of the robot, just above the back panel you will see that the robot also bears an FCC ID sticker. This is because the robot and remote are transceivers, using a solution based on the Nordic nRF24L01 IC. This IC is used in the AI-01 in "Enhanced Shockburst" mode, which uses a transceiver algorithm. The remote sends a packet of data, and the robot responds with an acknowledgement. So the AI-01 remote out of the box "does all the talking" so to speak in that it controls the action of the robot and the robot only talks back saying "roger, I heard you say drive forward". But the robot has the ability to send packets of data back. Changing the robot to do this is an exercise in software only. The hardware is ready to go for bi-directional communication.

ROBOT:
Robot Operation. The block diagram of inputs, processing and outputs are shown in figure 3. The PIC18F65J10 microcontroller is at the center. Inputs are on the left (for the most part, some pieces like the RF circuit are bi-directional) and outputs are on the right.

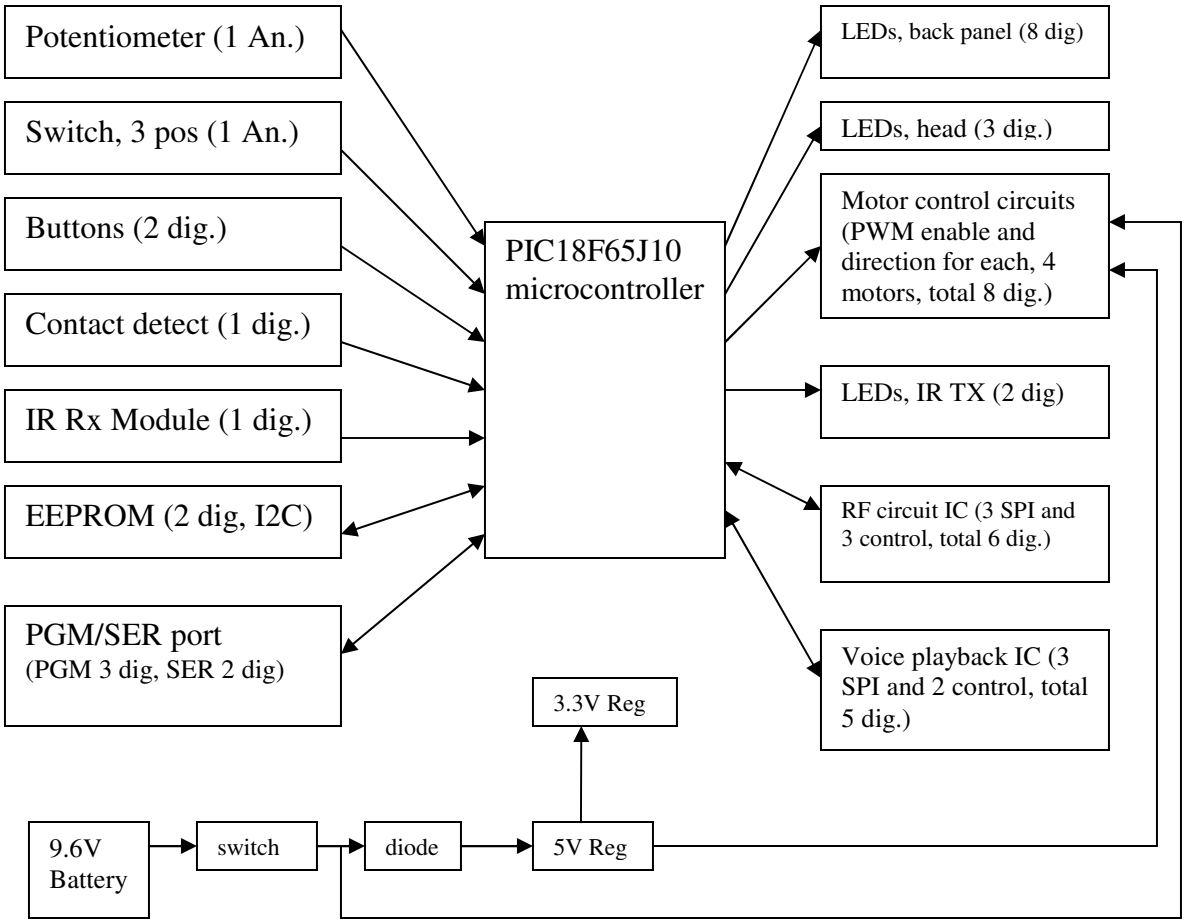

Figure 3: Robot Block Diagram

The robot has one electronics board so all elements of this diagram are on that board. The RF circuit's antenna is built into the PCB. Broadly, the robot has

Inputs:

Potentiometer, back panel, 1 analog input line
3 position switch, back panel, 1 analog input line
2 buttons, back panel, 2 digital inputs
Contact detector, electromechanical spring and pin, 1 digital input line
IR receiver module, 1 digital input line

Outputs:

LEDs, back panel, 6 yellow, 1 red, 1 green, 8 I/O lines

LEDs, head, 2 blue, 2 yellow, 2 red, 3 I/O lines
H-bridges ckt, Motor 1, 2 digital output lines
H-bridges ckt, Motor 2, 2 digital output lines
H-bridges ckt, Motor 3, 2 digital output lines
H-bridges ckt, Motor 4, 2 digital output lines
LEDs, IR transmit Left and Right, 2 digital output lines

Bi-directional:

RF circuit, 6 I/O lines, 3 SPI and 3 control (bi-dir interface)
Voice circuit, 5 digital output lines, 3 SPI and 2 control
EEPROM, external IC to microntroller, 2 digital lines, I2C interface (bi-dir)
PGM/SER port, 4 digital I/O lines, bi-dir

Power:

- PWR – 9.6V rechargeable battery, routed straight to H-bridge after main power switch, AUX power pin is after power switch and protection diode
- 5V – 7805 linear regulator, max 1A continuous current. From 9.6V battery after switch and protection diode. Used in logic for the motor control circuits.
- 3.3V – linear regulator from 5V supply, max 500 mA current. Main board supply for the micro, and all other circuits.

General operation: Robot takes input on the input lines which trigger different states in software. The outputs are driven depending on the state of software. The PIC micro used on the robot can be configured so that lines can be inputs or outputs. Analog in lines can become digital ins/outs. The reason that this operation statement is so general is that it is indeed the way the robot works, and says what YOU can do with it. It is very open ended. Again, note this document is not a software specification. The reader is directed to the data sheet for the Microchip PIC18F65J10 for detailed information on the micro's hardware capabilities.

Pot and 3-pos switch: Both are analog inputs. The pot's output is an analog voltage between roughly 0.1 V and 3.2V DC. Center position of pot is approx 1.63V. The 3 position switch will have output values of 0, 1.65, and 3.3V.

Contact detect: A very simple acceleration detection circuit based on a spring soldered onto a ground pad. The spring surrounds a pin which has pull up resistor to 3.3V, so by default the output is logic high (3.3V). When the robot is hit or accelerated to the left or right or up or down relative to the plane of the front of its body, the spring will be deflected to make contact with the pin, driving the contact pin at microcontroller to ground. Debounce of this signal is done in software (duration of logic low pulses is on order of 0.7 - 5 ms).

IR circuit is the well known obstacle detection circuit. The IR receiver module is the Sharp GP1UE261XK, optimized for 38 Khz modulated frequency. It is powered by 3.3V supply. The IR transmit LEDs are powered by 3.3V and are active low outputs on the micro pins.

User interface ports (AUX and PGM/SER) are covered in detail in later section of this document. Briefly, PGM (top row of 5 pins of the PGM/SER port) is the Microchip debug interface which can be used with the Microchip ICD2 or equivalent device to reflash the PIC micro. The lower 5 pins is the serial interface (SER) which can be used to interface the robot (and remote since it has the same port) to a computer's serial port for communication.

RF circuit is a transceiver circuit based on the Nordic nRF24L01 IC. This circuit has a range of about 100' outdoors, and 50' indoors. Actual ranges can vary. Default code provides for 1 Mbit/sec data rate max. The nRF24L01 Enhanced Shockburst mode is used by default which provides error correction and auto acknowledgement features. The SPI interface is used to communicate with the chip. An interrupt line is used to inform the micro when data is available or when error has occurred. Power is 3.3V. The RF circuit operates in 2 frequencies, XXXX and XXX Ghz. Individual node addressing is used to differentiate robot from robot, etc. See nRF24L01 data sheet for more information.

Motor Control Circuits: (see schematics for more detail) are driven by two output lines each from the micro. Lines are enable and direction. Enable is a PWM signal from 1 of 5 Capture/Compare lines (CCP) on the micro. PWM enable line gives speed control of DC motors. Frequency of PWM is 2.5 KHz. The TIP120/125 transistors which are the work horses of the motor control circuits restrict using a higher frequency. Directional control is done with one digital line for each motor control circuit. The DIR line routes through logic ICs that restrict an H-bridge circuit to being in a safe operation state.

REMOTE

The remote's block diagram is shown in figure 4. Again, inputs are on left. The remote RF circuit is shown on the right, but again note that the RF circuit is bi-directional on both robot and remote. The circuit is identical on both robot and remote, though on the remote it is physically located on a separate board and connected by a right angle header. The function is the same though.

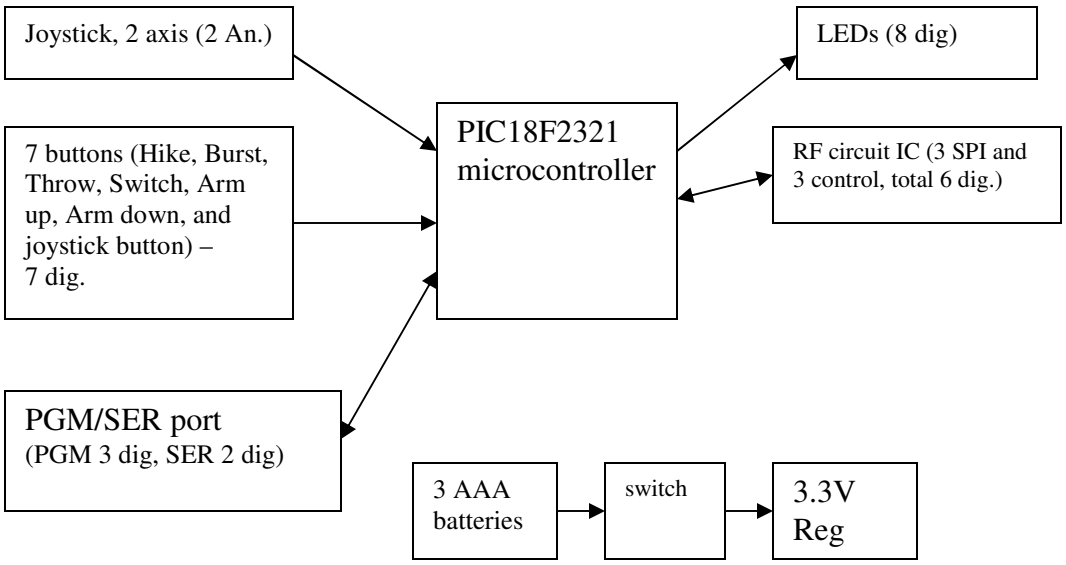
Joystick, 2 axis (2 An.)
7 buttons (Hike, Burst, Throw, Switch, Arm up, Arm down, and joystick button) – 7 dig.
PGM/SER port (PGM 3 dig, SER 2 dig)
PIC18F2321 microcontroller
LEDs (8 dig)
RF circuit IC (3 SPI and 3 control, total 6 dig.)
3 AAA batteries
switch
3.3V Reg

Figure 4: Block Diagram for AI-01 Remote Control

Remote Inputs:

Joystick, 2 axis so 2 analog inputs (also has digital button switch)
7 button switches so 7 digital lines

Outputs:

8 LEDs (6 yellow, 1 red, 1 green), 8 digital output lines

Bi-directional:

RF circuit, 6 digital lines, 3 SPI, 3 control

Power:

4 AAA batteries go into compartment on bottom. Battery voltage goes into 3.3V linear regulator, with 500 mA max output (same as used on robot). 3.3V is the only voltage used on the board (nRF24L01 has an internally generated 1.7V, see data sheet for more detail).

Operation description: The remote is based on the Microchip PIC18F2321 microcontroller. The remote's inputs are the joystick and buttons. Outputs are LEDs and the RF circuit. User operates joystick and buttons. Software analyzes these inputs and transmits a packet of data about every 60 ms that contains information about the state of the inputs.

Joystick is a 2 axis 10Kohm analog potentiometer. Output voltage is about 1.65V when in neutral position on X or Y axis. Min 100 mV to about 3.26V max.

Buttons. Active low digital inputs. Logic high (3.3V) on micro pin when button is released, logic low (0V) when pressed. The joystick also has a button switch built into it.

RF circuit: identical in operation to that of the robot.

LEDs: 6 yellow, 1 red and 1 green. Layout matches that of the robot to aid in programming address of the remote. Remote uses through hole LEDs though, whereas robot uses surface mount LEDs.

PGM/SER port is identical to that of the robot for pinout and physical configuration. Serial port is not active by default but can easily be activated in software. Note that the PGM interface for the robot multiplexes the PGD and PGC lines with the yellow LED lines. So if an active PGM/SER device is connected to the remote, yellow LEDs 1 and 4 may come on.

Schematic Diagrams for the robot and remote control are attached as Appendix A to this document for reference.

Chapter 2: The PGM/SER port

Figure 5 shows the pinout of the PGM/SER port as it appears when you look at the port on the robot's front after you remove the chest plate. This same pinout configuration is seen on the remote when facing the port on the remote's front side (that faces user during operation).

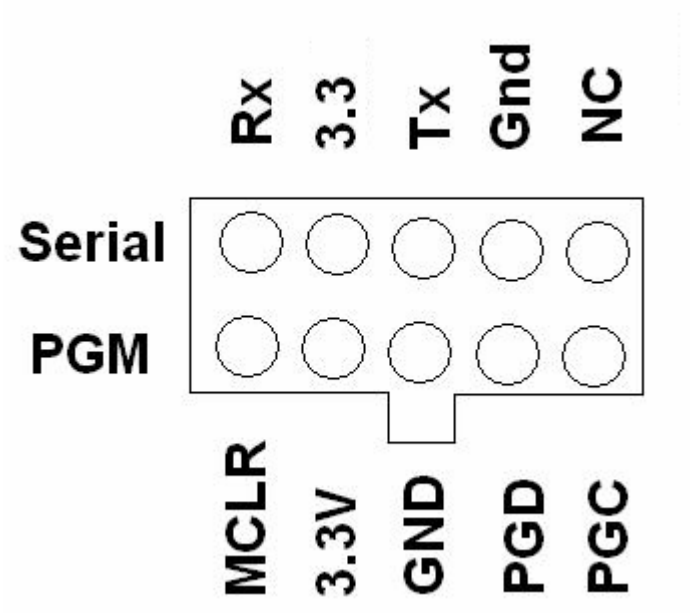

Figure 5: PGM/SER port pin out

Table 2 Describes the pins' functions.

Pin	Function
	SER (Serial port) is the top row of pins
Rx	Serial UART, microcontroller's receive pin
3.3	3.3V power
Tx	Serial UART, microcontroller's transmit pin
Gnd	Ground reference voltage
NC	Not Connected
	PGM (Program) is the bottom row of pins
MCLR	Microcontrollers MCLR pin – Master Clear is the reset pin on PIC microcontrollers. Note that on robot this is a full time MCLR pin. On the remote however, this pin is multifunctioned. On remote this pin is MCLR only during programming. During operation this pin is joystick button input)
3.3	3.3V power same as on SER port pins
GND	Ground, same as on SER port pins
PGD	PIC program/debug mode, data pin
PGC	PIC program/debug mode, clock pin

Table 2: PGM/SER port pin function

To access the PGM/SER port on the robot, you must remove the chest plate. Start by removing the 4 screws in the chest plate, then, gently pull the chest plate away as shown in figure 6 below.

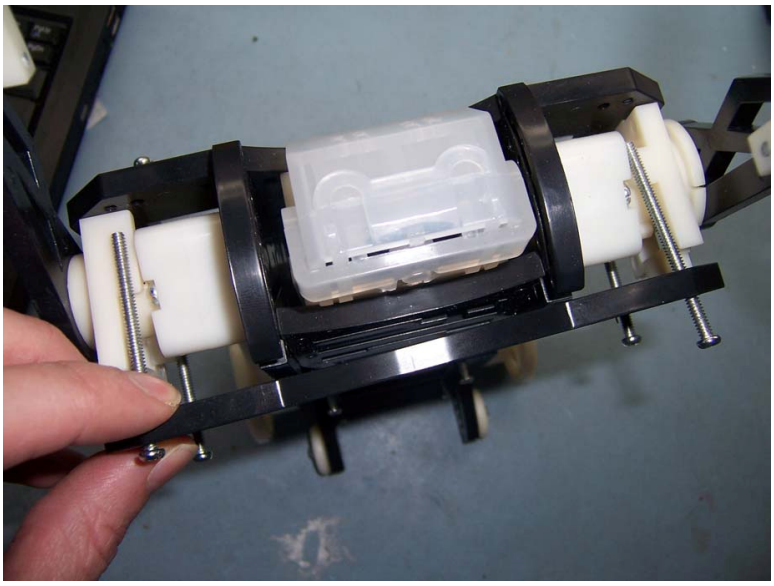

Figure 6: Removing the chest plate on robot to access the PGM/SER port

Then remove the inner chest plate by just pulling it away. Note that it is not absolutely necessary to remove this part but it may make connection of the PGM/SER cable easier.

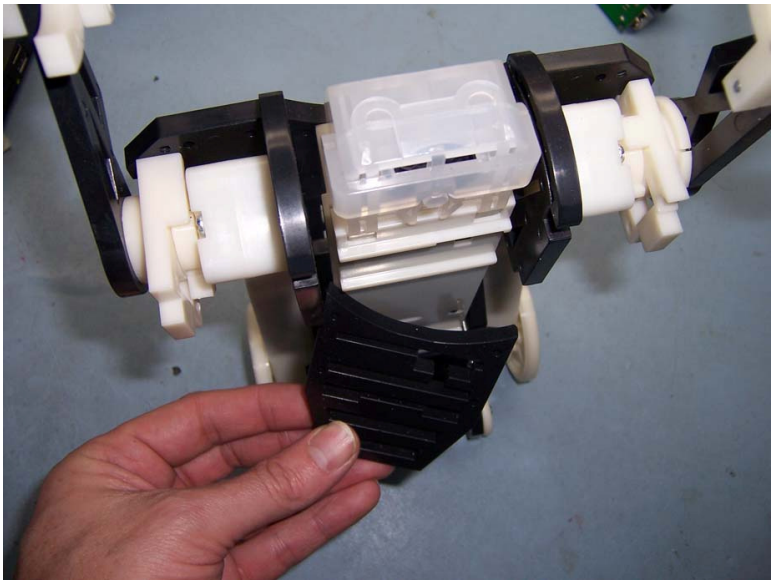

Figure 7: Removing inner chest plate

Figure 8 is a photo of the PGM/SER port as it appears on the robot's front, with the orientation of the cable.

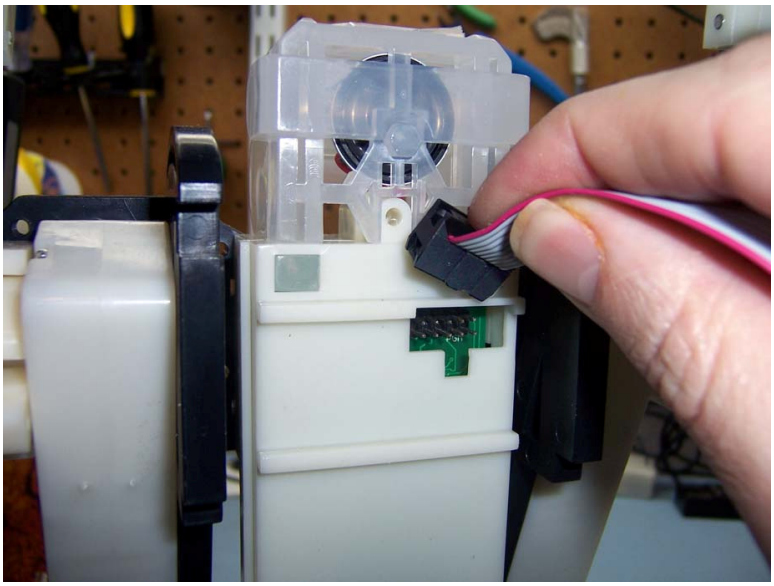

Figure 8: PGM/SER port on robot

You can drill or otherwise place a hole in the chest plate to facilitate a permanently exposed PGM/SER port. The area to cutout is already laid out for you in an indentation in the chest plate as shown in figure 9. Just remove the plastic in this area to create a permanent access port. Note that if you don't want to do this, you can also just leave out the chest plate screws and replace the chest plate. It will stay on by friction alone through quite a bit of force.

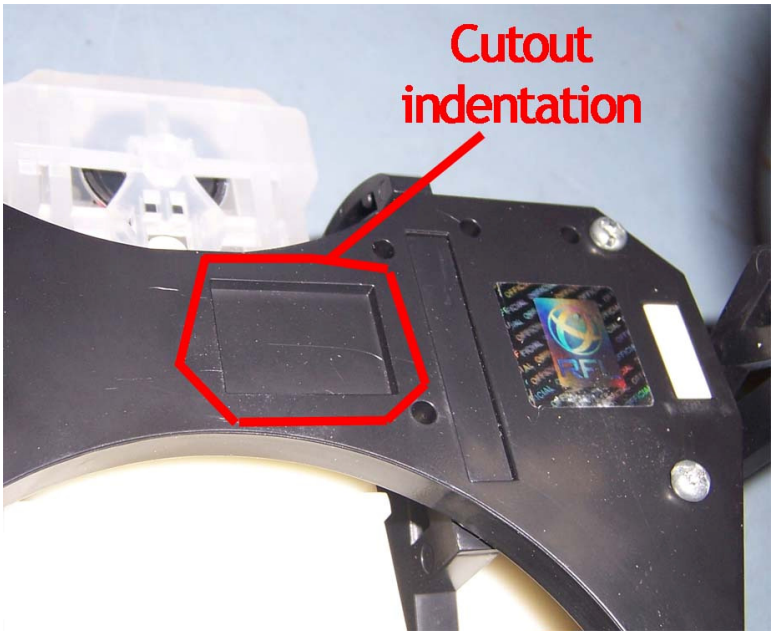

Figure 9: Chest cutout area for PGM/SER port

Figure 10 shows the location of the PGM/SER port on the remote control with a cable attached. To access the port on the remote you must remove a black rubber dust plug.

Figure 10: Remote control PGM/SER port location.

Operation with ICD2: The Microchip ICD2 is a debug interface device that allows a user to reflash program memory and also to step through code line by line in debug mode.

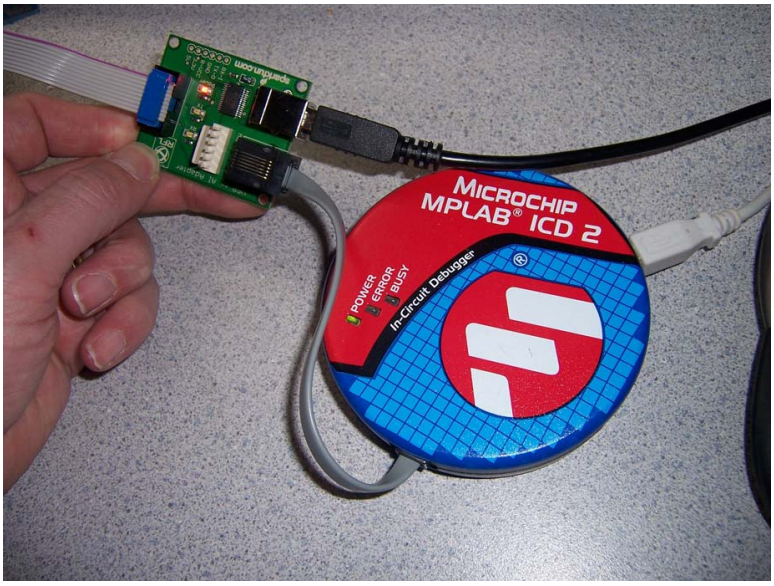

Figure 11: ICD2 connected to Sparkfun USB to AI adapter board

The AI-01 robot and remote microcontroller function normally with ICD2. You need a Sparkfun USB to AI Adapter board as shown (available from www.sparkfun.com, SKU DEV-08473). The ICD2 connects to the adapter board as shown.

Default Output of Serial Port: Function of the Serial port is user configurable. By default, the robot will print out "AI-01 Now Online" on reset.

The remote prints out the 10 data bytes that reflect the state of the remote's input controls in hex format. String out is "to XX XX XX XX XX XX XX XX XX XX". Table 3 explains the content of the 10 data bytes.

Byte	Content
0	Address – Contains the robot address, possible values 2,4,6,8,10,12. These are the robot's control channel 1-6 multiplied by 2.
1	Operating Frequency – Values are decimal 10 or 120 (2410 or 2520 MHz)
2	Data Direction (always relative to remote) – values are 0xC0 for out and 0x05 for in. Always 0xC0 in default code. The Data In definition is reserved for future use.
3	Mode and Bot is - Mode is upper nybble, Bot is lower nybble. Shows state of remote with use of the Switch and Hike buttons which are displayed on the red and green LEDs. By default, remote is in Huddle mode and Bot A (red LED is on an steady). If Switch button is pressed Bot = B. Pressing Switch sets Bot back to A. Play/Huddle mode is toggled by pressing Hike button. If in huddle LED is steady, play it flashes. If Mode = Play, nybble is 0xA If Mode = Huddle, nybble is 0x5 If Bot = A (red LED on), nybble is 0x1 Bot = B (Green LED) nybble is 0xE Example: Remote is set for RobotA, Play mode then this byte = 0xA1
4	Joystick X axis value (decimal 0-255), center nominal is 127
5	Joystick Y axis value (decimal 0-255), center nominal is 127
6	Button states – this byte shows the state of all the buttons. Each button is represented by a bit where 0 is button released and 1 is pressed Bit Button 7 Reserved 6 Joystick button 5 Up 4 Down 3 Hike 2 Switch 1 Throw 0 Burst
7	Throw state and speed byte. Bit 4 = Throw/notThrow, Bit 3:0 – speed/power (values ranging over decimal 8,9,10,11,12 or 13 depending on how long the button is held down). Note: Robot translates these into numbers into PWM settings for the throw motor where 8 is lowest setting at about 60% duty cycle. 13 is full duty cycle.
8	Reserved, always hex FF in default code
9	Reserved, always hex FF in default code

Table 3: Remote default serial output byte definition

For more information about use of the serial bootloader function, the user is directed to the AiSerPgmr User Manual.

Chapter 3: The AUX port

Figure 11 is a conceptual drawing of the AI-01 and shows the location of the AUX port on the AI-01's back panel controls. In general, the purpose of the AUX port is to give the end user access to the robot's on board battery power supply and 2 I/O pins for control of accessory devices.

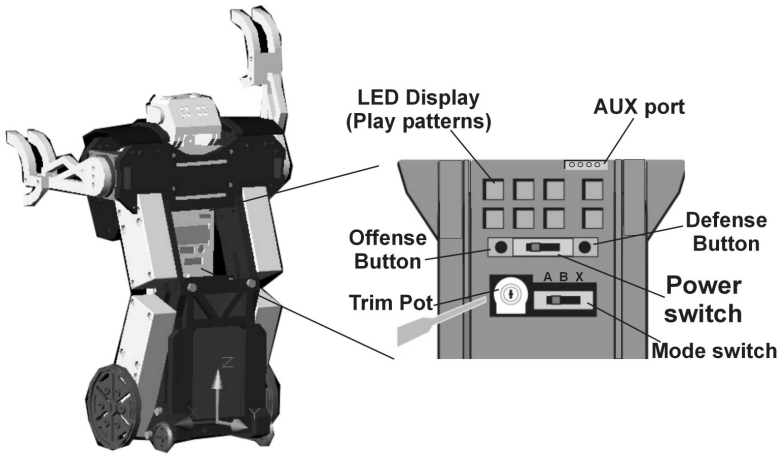

Figure 12: AUX port location on back of robot

The AUX port is a 4 pin 0.1" spacing header located on the AI-01's back panel. Pinout of the port is (left to right), AUX1, AUX2, Gnd, VCC. Figure 12 shows the pinout with greater detail to the back panel.

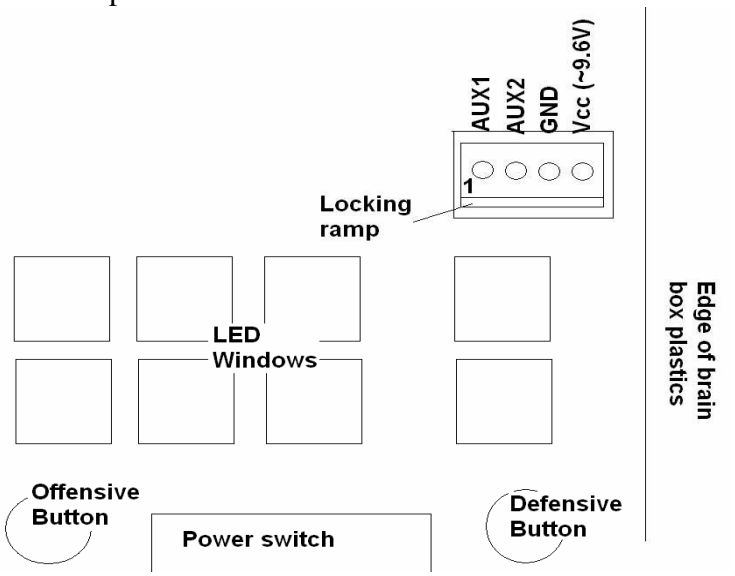

Figure 12: AUX port pinout detail

Pin	Data Direction	Function
AUX1	TTL Output, logic 0 and 3.3V	Default state during normal operation of robot is logic high. When remote joystick button is in pressed state, AUX1 pin will be low (0V). When joystick button is released, AUX1 pin is high (3.3V).
AUX2	TTL Output, logic 0 and 3.3V	Default state is logic low. Pin is logic high when remote is in "Play" mode, low when in "Huddle" mode. If no remote signal detected, pin goes to logic low. 10 mA sink/source capability.
Gnd	Ground Ref	0 volt reference pin for connecting accessory reference
VCC	Power, Battery Voltage	Direct access to battery voltage after protection diode, nominally 8.9VDC. Current draw by an AUX device should not exceed 300 mA continuously or robot's other functions may degrade.

Table 4: Pin function definitions with default robot code

AUX1 and 2 are tied to the AI-01's PIC18F65J10 microcontroller via 150 ohm series resistors for isolation. The pins are also protected against ESD damage to the microcontroller using BAV-99 diodes.

The 18F65J10 microcontroller can be reprogrammed by the user and the pin function of the AUX header reassigned. Options for the AUX1 and 2 pins are digital I/O, or Analog input. AUX1 is PortA pin3 of the microcontroller (AN3, analog channel 3), and AUX2 is PortA pin 5 (AN4, analog chanel 4). For more detail on the operation of the pins for user configurability, see the data sheet for the Microchip PIC18F65J10 microcontroller.